SPACEBORNE THERMAL INFRARED DATA ANALYSIS OF METEOR CRATER, ARIZONA: ANALOG FOR THEMIS DATA OF A SMALL IMPACT CRATER IN SYRTIS MAJOR

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Introduction: Thermal Infrared (TIR) data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) have been used to map the Meteor Crater ejecta lithologies. This has many applications to current TIR data being returned from Mars by the Thermal Emission Imaging System (THEMIS) instrument. Terrestrial multispectral images can be used as proxies for constraining TIR data of Mars [1,2]. A fresh, small (~1 km diameter), simple impact crater in Syrtis Major Planitia has been mapped using a similar methodology to that employed at Meteor Crater. Image end member spectra are shown and potential future investigations are listed.

Background and Application to Mars: Multi-spectral visual, near infrared (collectively, VNIR), and TIR data of the martian surface are currently being returned by THEMIS. However, the interpretation and application of THEMIS TIR data requires a knowledge of the instrument's spatial and spectral constraints along with an understanding of complicating surface factors such as dust and atmospheric effects. ASTER provides a comparable data set to THEMIS due to its similar spatial and spectral resolution [1, 2].

Within the TIR region, most major rock-forming minerals have significant absorption features [3]. These absorption bands change in morphology due to differences in the Si-O bond strength as well as the degree of shocked metamorphism [4]. Further, TIR data have been shown to add linearly and thus be easily interpretable [5,6]. The composition and aerial abundance of each lithology can be calculated due to the fact that the emissivity spectrum from a surface is a combination of the emissivities from each component in proportion to its aerial percentage [5].

Previous studies have investigated the characteristics of dust on Mars. The atmosphere of Mars has been modeled as containing dust that is 1-2 µm in diameter whereas the high albedo regions are covered with dust particles up to 40 µm in diameter [7,8]. Significantly thick dust coatings can effect the interpretation of TIR spectroscopy [9]. However, low albedo, fresh-looking impact craters have not been present long enough for significant dust to accumulate.

According to size versus frequency diagrams, non-degraded, small impact craters outnumber large craters on unmodified planetary surfaces and are of younger age. Over 43,000 impact craters with diameters > 5 km have been catalogued on the surface of Mars [10]. Younger impact craters will have less erosion and denudation, a well-preserved ejecta blanket, and less dust at the surface, making them excellent sites for TIR observations of the surface composition. Of further interest is being able to identify the inner-crater stratigraphy and the distribution of those units within the ejecta blanket. This provides insights on the geology and local climatic conditions of the region post crater formation.

Instrumentation: ASTER is a multispectral imager on the Terra spacecraft and is part of NASA's Earth Observing System. ASTER has fourteen bands from the visible to the thermal wavelengths, including five in the TIR at 90 meter spatial resolution and three bands in the VNIR at 15 meter spatial resolution [11]. It has been operational since December, 1999 and has collected seven images of Meteor Crater, Arizona.

THEMIS, a multispectral imager on the Mars Odyssey orbiter, has returned images in the VNIR and TIR wavelengths since February 2002. The primary objectives and science goals of THEMIS are to determine the mineralogy and petrology of the surface of Mars utilizing the hyperspectral data of the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) in order to study small-scale geologic processes and potential future landing sites [12]. THEMIS has ten TIR bands from 6.5 µm to 15.5 µm at 100 meter spatial resolution. However, the atmosphere of Mars is opaque over Band 10 (14.8 µm), so no surface information is returned over this bandwidth. THEMIS also has five bands in the VNIR at 18 meter spatial resolution. VNIR data has yet to be collected over the target.

Terrestrial Analog: Meteor Crater is located in semi-arid, north-central Arizona and is estimated to be 50,000 years old, making it one of the most recent and well-preserved impact sites on Earth [13]. The simple, bowl-shaped crater is 180 meters deep and 1.2 km in diameter with an eroded rim standing 30-60 m high. The local geology consists of three flat-lying sedimentary members with well-documented lithologies and contrasting TIR spectral signatures. The oldest unit sampled by the impact is the Permian Coconino Sandstone. Above the Coconino are the Permian Kaibab Limestone and a thin veneer of the Triassic Moenkopi Formation. The crater ejecta consists of the same lithologies as above, but in inverted order of deposition.

It has been shown that an image end member analysis using the TIR wavelengths can be used to map the lithologies distributed in the Meteor Crater ejecta blanket [14]. However, the airborne Thermal Imaging Multispectral Scanner (TIMS), with a much higher spatial resolution (≈11 m), was used in the earlier study. Still in question and what this research seeks to answer is if the lower resolution THEMIS data sets can be used in a similar way to identify the lithologic end members on Mars. Using ASTER TIR data as a proxy for THEMIS and emission spectra from samples collected at Meteor Crater, an ASTER image end member analysis and an ASTER sample end member analysis were performed. The two compare favorably to each other [15] and to the earlier high-resolution TIR image end member deconvolution [14]. All were validated by field work.

The mapping approach described above fails where lithologies with small aerial percentages and/or similar TIR spectral signatures are present. This is expected where using 90 or 100 meter pixels as image end members [14]. Additionally, using ASTER, the extent of a wind streak composed of Coconino sandstone agrees with the results of field work and TIMS [14].

Crater in Syrtis Major Planitia: The THEMIS TIR scene I01297001 contains a fresh, small (rim to rim diameter ≈ 1 km) impact crater located in the southern highlands at approximately 4º S, 59º E (crater shown in Figure 1). The region is abundantly cratered and has an overall low albedo. Previous studies of thermal inertia have found the low albedo regions of Mars to be composed of course-grained particles (200–500 μm) [16]. Deconvolution of TES spectra also show calcium pyroxene and plagioclase to be the dominant minerals of the Syrtis region [17].

The preliminary THEMIS TIR data are uncalibrated and given in Digital Numbers (DN's). Radiance and emissivity spectra have not been extracted from the preliminary TIR data. Three spectrally-distinct THEMIS TIR image end members were identified using standardized image processing tools. These are shown in Figure 2 and are comparable to previous spectra of the southern highlands [6,17,18]. The continuous ejecta blanket (CEB) contains a lithology (labeled as 'CEB' in Figure 2) that is not found in the surrounding terrain ('EM1' & 'EM2'). The extent of the CEB varies from 1.7 km to 5.1 km around the crater rim.

Conclusion: Using calibrated radiance data, emissivity spectra can be extracted in order to determine the composition of the crater's CEB and surrounding terrain. Because ejecta represents the underlying pre-impact lithologies, the mineralogy of the local subsurface can be determined, even in areas where significant dust mantle the surrounding plains units. Additionally, estimates of pre-impact stratigraphy and current regolith thickness could be investigated.

In conclusion, ASTER TIR data of Meteor Crater make excellent analogs of THEMIS TIR data of the aforementioned fresh, small, simple impact crater and similar craters on Mars. Future investigations with calibrated THEMIS data will investigate various crater properties listed here which, in turn, should better constrain the primary science objectives of the THEMIS instrument.

References: [1] Ramsey M.S. (2002), *Mars Infr. Spect.*, LPI Contr. 1148, pp 2016. [2] Ramsey M.S. (2002) AGU 83(47) abstract P62B-12. [3] Salisbury J.W. and L.S. Walter (1989) *JGR 94*, 9192–9202. [4] Johnson J.R. et al. (2002) *JGR 107*(E10), 10.1029/2001JE001517. [5] Ramsey M.S. and P.R. Christensen (1998) *JGR 103*, 577-596. [6] Christensen P.R. et al. (2000) *JGR 105*, 9609–9622. [7] Tomasko M.G. et al. (1999) *JGR 104*, 8987-9008. [8] Moore H.J. et al. (1999) *JGR 104*, 8729-8746. [9] Johnson J.R. et al. (2002) *JGR 107*(E6) 10.1029/2000JE001405 [10] Barlow N.G. (2000) *LPSC XXX*, abstract #1475. [11] Abrams M. (2000) *Int. Journ. Of Rem. Sens. 21*, 847-859. [12] Christensen et al. (1999) *Mars Miss. Wrkshp*, pp 16-18. [13] Shoemaker E.M and S.W. Kieffer (1974) *Geology of Meteor Crater, Arizona*, 66 pp. [14] Ramsey M.S. (2002) *JGR 107*(E8) 10.1029/2001JE001827. [15] Wright S.P. and M.S. Ramsey (2002) *Sol. Sys. Rem. Sens. Symp.*, LPI Contrib. No. 1129, pp 4027. [16] Palluconi F.D. and H.H. Kieffer (1981) *Icarus 45*, 415-426. [17] Bandfield J.L. (2002) *JGR 107*(E6), 10.1029/2001JE001510 [18] Smith M.D. et al. (2000) *JGR 105*, 9589-9607.

Figure 1. (below) Fresh crater in Syrtis Major shown in THEMIS TIR Band 3 (λ = 7.93 μm)

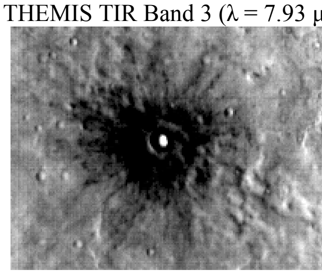

Figure 2. (below)